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A STUDY OF THE RELATION OF TRANSPiration TO THE SIZE AND NUMBER OF STOMATA

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Considerable work has been done in determining the quantity of water lost from various plants under various conditions. Several extensive investigations have been conducted with a view of determining stomatal values for various species. Although several important researches have been conducted concerning the stomatal regulation of transpiration, very little has been done on the amount of transpiration in relation to the size and number of stomata per unit of transpiring surface. It was my aim to determine whether any relation exists between the amount of transpiration and the number of linear units of stomatal aperture per unit of leaf surface.

I. HISTORICAL

Probably the earliest attempt to determine quantitatively the amount of water lost in plants was by Hales (7) as early as 1727. Hales not only determined the amount of transpiration per square foot of leaf area for the sunflower, cabbage, grapevine, lemon tree, and apple tree, but he also found that the amount of transpiration varied during the day and night hours and also with changes in physical factors.

Clapp (4) determined the quantity of water in grams transpired (GM^2H) per square meter of leaf surface per hour for day and night for thirty common greenhouse plants both under greenhouse and under "standard" conditions, but she used only one individual of each species in her experiment. In computing the transpiring surface she considered only the upper surface of the leaf. She also found that there are two extremes of transpiration, the greatest amount in the early afternoon when the light is strongest and the minimum amount during the night when the stomata are closed.

The work on transpiration up to 1904 is summarized in Burgerstein's excellent work on transpiration in plants (3). He discusses the various phases of transpiration, methods for its determination,

the effect of leaf structure and of external factors on transpiration, and whether transpiration is a process of vital significance to the plant or whether it is a necessary evil to the plant.

The work on the size and number of stomata for various species is rather limited but several rather extensive investigations have been conducted along this line of work. Several early investigators—Humboldt, 1786; Hedwig, 1793; Kieser, 1815; Lindley, 1832; Krocker, 1833; Meyer, 1837; Unger, 1855; and Morren, 1864—determined stomatal values for a number of different species, the results of which are given in a summary table by Weiss (1865).

Weiss in his very extensive work (13) gives the length, breadth, and area of stomata as well as the number of stomata per unit of area both on the upper and lower surface for 167 of the more common European plants. The results of these early investigators do not always agree and often their figures are very different. This may be explained as being due to the insufficient instruments for measuring, but more probably because different men used plants which were grown under different conditions or even used different varieties.

Weiss observed that stomata may be present on underground stems and aerial stems as well as on leaves. He also states as a result of his observations that the presence of stomata is not limited by the surrounding medium; in other words, stomata may be present on parts of plants which are in air, water, or earth.

Eckerson (5) determined the stomata-quantities for about 38 common greenhouse plants. She gives a valuable table in which are recorded the length of the guard cells and of the pore of the stomata and the number of stomata per sq. mm. of upper and lower leaf surface for each species.

The most important work on transpiration in relation to stomatal movement is by Lloyd (10). In his experiments on cuttings of *Verbena ciliata* and *Fouquieria splendens* he discovered that the rate of transpiration may undergo sudden and wide changes without any corresponding changes in the size of the stomatal aperture. From this he concludes that stomatal regulation does not occur, though, of course, conservation of contained water follows upon complete closure of the stomata; but it has not yet been proven that this ever occurs.

The plan of my work was to determine the quantity of transpiration simultaneously for a number of species with various stomatal values

and then determine what relation, if any, exists between the amount of water lost and the amount of stomatal aperture in linear units, per unit of leaf area.

II. METHOD

Various methods have been devised and employed for the quantitative determination of transpiration both directly and indirectly. It seems that the results, in order to be of much value, should be obtained from plants which at least approach the natural conditions of the plant. Some investigators have confined their investigations

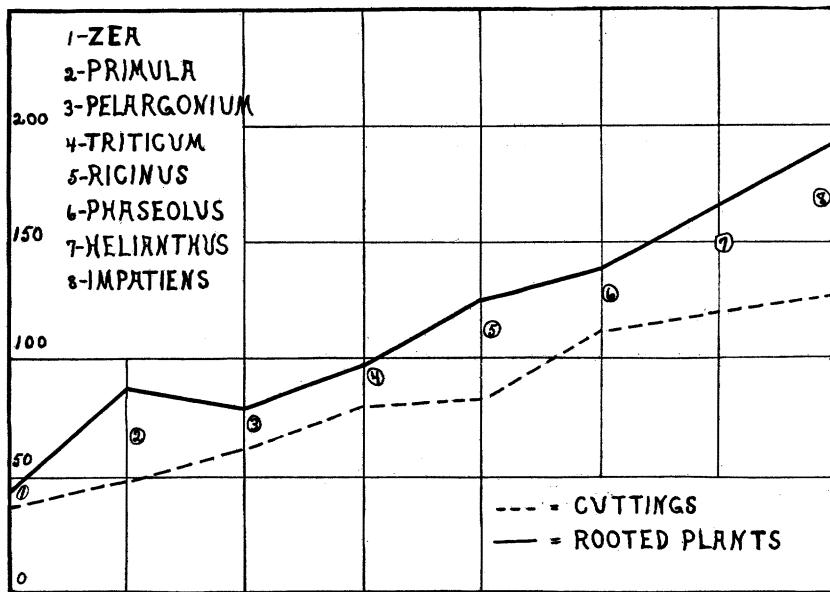


FIG. 1. Showing the amount of transpiration in mg. per hour per sq. dc. leaf surface for cuttings and rooted plants of the several species.

entirely to observations upon removed parts of plants, small cuttings of branches, or even single leaves. Lloyd (10) worked only with cuttings in his experiments on stomatal movements. Freeman (6) questions the value of determinations of water loss made from detached parts of plants except where only comparative results are desired, which was the case in Lloyd's work (10). However, it is doubtful whether the limited number of experiments performed by Freeman (6)

would warrant us in drawing the conclusion which he makes in regard to the relation of the amount of transpiration from rooted plants and detached cuttings of plants.

In order to satisfy myself as to the possibility of a relationship between the amount of water lost from plants with their roots and plant-parts without roots, an experiment was conducted with five cultures of cuttings in water and ten cultures of rooted plants in jars for each of eight species.

The two sets of jars were run simultaneously for 24 hours from 6 o'clock P. M. January 4, to 6 o'clock P. M. January 5, 1915. The results of the experiment are given in the form of curves in figure 1. The two curves show that the water loss in cuttings is about 20 or 30 percent less than the amount lost by the same plant under similar conditions when rooted in a jar. In every case the amount of transpiration was less per unit of leaf surface from cuttings than from rooted plants. The cuttings consisted of short stems with from two to five leaves and were removed from the plants under water. The quantity of transpiration is recorded in milligrams per hour per square decimeter of leaf surface.

In brief, the method employed in the following experiment consisted in sealing jars so as to prevent all loss of water except that which is lost through the plant; determining this loss by weighing; and then computing the amount of loss per unit of leaf area and stomatal aperture.

1. Selection and Preparation of Plants

In selecting the species used in this experiment several important considerations had to be kept in mind. Only plants with simple stomata were taken; that is, plants with stomatal elaborations such as pits, plugs, many hairs or extremely sunken stomata could not be used in this work so as to bring us face to face with the one factor, namely, the relation of the size and number of stomata to the amount of water lost.

The species had to be chosen so as to present the widest possible range in size of stomata. Only those plants could be selected which could be readily grown under greenhouse conditions such as those under which the experiment was performed: lilacs and cottonwoods were started, but shed their leaves and failed to send out a new set of normal leaves; plants of *Datura stramonium* were started

from seed but the plants grew very slowly and were so much stunted they could not be used in this work. Lastly only those plants could be used which would attain a fair size and maintain a reasonably uniform rate of growth while the experiment was performed. (See Table I.)

2. Preparation of the Jars

Most of the plants with the exception of *Pelargonium zonale* and *Primula sinensis* were started in flats from seeds. While the plants were still young they were carefully transplanted into the jars where they remained unsealed until they were large enough to use in the determination of transpiration. The plants of Primula and Pelargonium were healthy greenhouse plants which were transplanted directly into the jars and then were left on the greenhouse bench for several weeks before sealing for the experiment.

Large stone crocks of two sizes were used for containers; gallon crocks were used for the large plants, while one-half-gallon crocks were used for the smaller species. On the bottom of each jar was placed an inverted three-inch flower pot filled with gravel. Around the flower pot about one centimeter of sand was spread over the bottom of the jar. A glass tube with a 1 cm. bore was inserted into the hole in the bottom of the inverted flower pot and the tube extended about 10 cm. above the surface of the paraffin when the jar was sealed. This tube was used for watering the plant. The flower pot with gravel in it rapidly absorbed the water and the sand spread the water evenly over the bottom of the jar. Another tube was put in the jar so as to act as an aerating system for the soil when the jar was sealed. Then the soil was placed in the jars and the plants were planted in them. The number of individuals of each species that were placed in one jar varied from one to several, depending upon the size of the plants. (See Table I.) The cotyledons which still happened to be on the plants at this time were removed when they were transplanted.

After the plants had stood in the jars from one to several weeks, and had become well established they were ready to be sealed. The kind of seal used is that which was used by Briggs and Shantz (1) except that a little harder grade of paraffin was used. A mixture of eight parts of about 60° melting paraffin and two parts petrolatum was taken; however, the exact proportions were not determined in every case. The mixture was heated to melting and was then poured over the surface of the soil so that upon cooling it made a perfect seal.

In order to prevent the warm paraffin from doing any possible injury to the stem of the plants partially cooled strips of paraffin were first wrapped around each stem at the surface of the soil where the hot paraffin would otherwise come in contact with the stem. Each jar was marked by writing a number on the paraffin surface.

After the jars had been continued for several weeks the paraffin began to draw away from the edges of the jar slightly. In order to determine any possible error due to evaporation from the edge of the jar a number of jars were reweighed several times after the plants had been removed to see whether any water was lost by evaporation, but this was found to be very small or sometimes so small that it could not be detected by weighing from day to day. After removing the paraffin from the jars I found that it had run down between the edge of the soil and the stone crock several centimeters and still formed a very tight seal near the surface of the soil so that very little water could escape.

3. The Determination of Water Loss

A week after the jars had been sealed I took the first weighing for determining the amount of water lost. The amount of water lost was computed from the decrease in the weight of the jar between the intervals of weighing. At first the jars were weighed twice daily, between six and seven o'clock A. M. and between six and seven o'clock P. M. Later the weighings were taken only once each day in the evening, while some of the final weighings were taken at intervals of two or three days; but the jars were always weighed between six and seven o'clock P. M. For weighing I used a "micrometer scale" which has a capacity of 18,000 grams and weighs very accurately down to two or three grams.

The loss of water from the jar was replenished at intervals of two or three days through the glass tube which was inserted for that purpose. The amount of water added at one time was approximately the amount that was lost by the plants during the interval since the last addition of water, and was added in the evening between seven and nine o'clock.

4. The Determination of Leaf Areas

Numerous methods have been employed from time to time for the determination of leaf areas, but it was found impracticable to use

any of these methods without modification. It was impossible to use the solio paper method which was employed by Sampson and Allen (12), for it necessitated the making of many thousands of leaf prints. I made a number of preliminary determinations of the leaf areas of a number of plants by comparative weights, that is by weighing a given area of leaves which was determined by a Ganong's leaf-area cutter and then weighing the entire leaf area of a plant, from this proportion I determined the total leaf area of the plant. Then I also determined the leaf area of the same plants by making leaf traces and then computing the area by a planimeter. I found that the planimeter method was not only the most accurate but also the most practicable method for this problem. I found that the weight of one square centimeter of leaf varied from 1 to 100 percent from the average weight, depending upon the part of the leaf from which it was taken. The loss of water from the cut leaf sections is also very great especially if the leaves are not weighed immediately. By the weighing method the leaf area had to be found at the same time in all the plants of one species because the amount of photosynthate in the leaf at any given time varies with the time of day as well as from day to day. This would necessitate the determination of the weight per unit area each time it was desired to determine the leaf area for a number of plants.

By the use of the planimeter one can find the leaf area of a plant regardless of the amount of water or photosynthate in the leaf and one can use the same method for almost any number or kind of plant at any time. But, because of the enormous number of leaves of which I had to find the area, it was found necessary to modify the method somewhat. I found that each species had a large number of leaves in each plant which were almost of the same size, so I sorted the leaves of each plant into five piles and measured the area of one leaf of each pile and then multiplied the area of one leaf by the total number of leaves in that particular pile and then I computed the total leaf surface for each plant in square centimeters, considering both the upper and lower surface of each leaf.

Petiolar and stem areas were not considered as transpiring surfaces. It was found that these organs were practically free from stomata and the water loss from the same was very small in the plants used in this experiment.

The leaf area was determined for each plant at the end of the experiment. Since most of the plants were small and had a small

amount of leaf surface to begin with, compared with the leaf surface at the end of the experiment, the increase being due to growth, I had to make a correction for the increased leaf area. I considered the increase in transpiration as being proportional to the increase in leaf surface and divided the total leaf area by two to find the average leaf area during the entire period when the plants were used. This would be taking the leaf surface as zero to begin with but this discrepancy is balanced by the leaves which died and were removed from the plants during the progress of the experiment. This method was employed for all of the species which were started from seed. In the case of *Pelargonium* and *Primula*, two slow growers, where mature plants were used, I used the entire leaf surface as was determined at the close of the experiment. What little growth took place was offset by the loss of several dead leaves which were removed from each plant.

5. The Determination of the Number of Stomata

For determining the number of stomata I used a Spencer microscope with a micrometer scale. The value of the scale and of the field of the microscope were determined with a stage micrometer. The field was divided into quadrants by drawing very fine threads of balsam over the eyepiece micrometer. In those plants which had an epidermis which could be easily removed I mounted pieces of epidermis in absolute alcohol and then stained them with a weak solution of iodine. In the plants from which the epidermis could not be removed readily I counted the stomata "in situ" by the method suggested by Lloyd (9).

The stomatal counts were determined from an average of 30 to 50 sq. mm. each for the upper and lower surface from five or more leaves taken from as many different plants. Only fairly mature leaves were used and from these the fields were taken at random on the different parts of the surface.

6. The Determination of the Size and Area of Stomata

After determining the number of stomata for the several species the next process was to determine the size of the stomata for the same. In this process I employed the method so successfully used by Lloyd (10), Eckerson (5), Renner (11), and Livingston (8), in fixing the stomata so that they will not shrink and lose their shape and actual

dimensions. This method is based upon the rapidity with which alcohol dehydrates the guard cells when bits of epidermis are dropped in absolute alcohol immediately after they are removed from the leaf. When once dehydrated these cells become hard and remain permanent in size and shape even if they are afterwards mounted in water.

Since Lloyd (10) and Eckerson (5) found that the stomata are open widest at about 10 o'clock A. M., I removed bits of epidermis at this time of the day on bright clear days, placed them in vials of absolute alcohol and then determined the length and breadth of both guard cells and pores for about 25 to 50 stomata for each leaf surface for the several species used. From these data I also computed the area of one stoma and the amount of stomatal aperture and the number of linear units of stomatal pore per unit of leaf area for upper and lower surface.

III. EXPERIMENTAL

The following tables with short explanations and discussions represent briefly the scope and results of this investigation.

TABLE I

Showing the Species and the Number of Individuals of Each Used and When Each Were Studied

Series	Species	Date	No. of Jars	No. of Plants in Each Jar	Total No. of Plants
1.	<i>Helianthus annuus</i> L.....	11 days—Nov. 4-15, 1914	10	2	20
2.	<i>Helianthus annuus</i> L.....	5 days—Dec. 20-24, 1914	10	4	40
1.	<i>Impatiens sultani</i> Hook.....	30 days—Nov. 4-Dec. 4, 1914	12	2-3	30
2.	<i>Impatiens sultani</i> Hook.....	25 days—Dec. 10, 1914— Jan. 3, 1915	6	3	18
1.	<i>Pelargonium zonale</i> Willd.....	20 days—Nov. 4-24, 1914	10	1	10
2.	<i>Pelargonium zonale</i> Willd.....	40 days—Dec. 10, 1914— Jan. 18, 1915	10	1	10
1.	<i>Phaseolus vulgaris</i> L.....	25 days—Nov. 4-29, 1914	10	2-4	32
2.	<i>Phaseolus vulgaris</i> L.....	40 days—Dec. 10, 1914— Jan. 18, 1915	10	4-6	48
1.	<i>Primula sinensis</i> Sabine	40 days—Nov. 30, 1914— Jan. 8, 1915	10	1	10
1.	<i>Ricinus communis</i> L.....	60 days—Nov. 4, 1914— Jan. 4, 1915	10	2-3	21
1.	<i>Triticum sativum</i> Lam.	20 days—Jan. 3-23, 1915	8	10	100
1.	<i>Zea mays</i> L.....	30 days—Nov. 4-Dec. 4, 1914	10	4	40
2.	<i>Zea mays</i> L.....	30 days—Dec. 19, 1914— Jan. 18, 1915	10	4-5	45
Total.....			128		424

Table I briefly shows the extent of the work performed. The first column of the table gives a list of the species used. The number before the name indicates the number of the series for that species. With several exceptions two series were performed for each species. The second column indicates for how many consecutive days the transpiration was determined for each series and also the date when the work was carried on. The third column gives the number of individuals in each jar and the last column contains the total number of plants used in this investigation.

TABLE II

Showing Average Amount of Transpiration from the Various Species Used in Series I

Species	Total Time in Days	Total Water Loss in Gm.	Total Leaf Area in Sq. Cm.	Average Transpiration in Mg. per Hour per Sq. Dc. Leaf Surface
<i>Helianthus annuus</i>	II	8,027	20,000	151
<i>Impatiens sultani</i>	30	10,862	6,200	243
<i>Pelargonium zonale</i>	20	8,930	38,000	50
<i>Phaseolus vulgaris</i>	25	12,440	13,400	155
<i>Ricinus communis</i>	60	25,897	8,600	209
<i>Zea mays</i>	30	23,047	41,000	78

TABLE III

Showing Average Amount of Transpiration from the Various Species Used in Series II

Species	Total Time in Days	Total Water Loss in Gm.	Total Leaf Area in Sq. Cm.	Average Transpiration in Mg. per Hour per Sq. Dc. Leaf Surface
<i>Helianthus annuus</i>	5	1,440	7,200	166
<i>Impatiens sultani</i>	25	5,805	3,800	255
<i>Pelargonium zonale</i>	40	11,610	18,600	65
<i>Phaseolus vulgaris</i>	40	15,200	10,100	156
<i>Primula sinensis</i>	40	6,580	9,200	75
<i>Triticum sativum</i>	20	1,900	5,100	79
<i>Zea mays</i>	30	4,700	8,024	82

Upon examining Tables II and III it will be found that the absolute amount of water lost for the various species varies very much because of the variation in the total amount of leaf surface in the several species. It will also be noted that the average quantity of water lost per square decimeter of leaf surface, average of upper and lower surface, varies from a minimum of 50 mg. in Pelargonium to a

maximum of 235 mg. in *Impatiens* per hour, average of day and night transpiration for the average of ten jars for about 40 days.

The third column of Table II shows the total amount of water lost in grams by all the jars of each species used in series I. Column four shows the total, upper and lower, leaf surface in square centimeters for each species used in series I. Column five shows the average amount of water transpired for each square decimeter of leaf surface per hour for each species. Table III records the same data for the second series (Series II).

A comparison of the results of the two tables (Tables II and III) shows that the average amount of water transpired by each species as determined in the two series of plants varies but slightly. The largest difference is found in *Pelargonium zonale* and this is well accounted for by the fact that I accidentally used a different variety of *Pelargonium* for the second series. The results of *Helianthus annuus* may have been modified by an early attack of *Erysiphe cichoracearum*, which prevented me from continuing the cultures for a longer period than five days in the second series. The first eleven days of weighings which were obtained from the first series were taken before there was any evidence of Erysiphe and, I think, represent normal transpiration.

TABLE IV

Showing the Minimum, Mean, Average, and Maximum Number of Stomata in One Square Millimeter Leaf Surface

Name of Species	Lower Surface				Upper Surface			
	Min.	Mean	Av.	Max.	Min.	Mean	Av.	Max.
<i>Phaseolus vulgaris</i>	131	269	250	327	28	40	40	50
<i>Ricinus communis</i>	79	156	121	172	35	68	52	76
<i>Zea mays</i>	91	103	101	110	51	61	60	83
<i>Primula sinensis</i>	49	87	84	112	0			
<i>Pelargonium zonale</i> 1.....	32	52	52	72	9	18	19	24
<i>Pelargonium zonale</i> 2.....	190	210	215	232	4	9	8	11
<i>Impatiens sultani</i>	105	140	143	180	12	37	29	70
<i>Triticum sativum</i>	12	21	21	27	35	46	46	55
<i>Helianthus annuus</i>	125	170	172	198	27	70	71	90

Table IV shows the number of stomata per square millimeter leaf surface for each of the several species. It will be noticed that all but one species, *Triticum sativum*, have fewer stomata on the upper surface than on the lower surface. I found that the number of stomata varied considerably in different parts of the same leaf. On

the other hand, I noticed that for similar areas of the various leaves examined the number of stomata was more or less constant for the species. I tried to take the upper and lower counts for each leaf from similar or corresponding areas.

The number of stomata per square millimeter varies from an average of a maximum of 250 in *Phaseolus vulgaris* to a minimum of 21 in *Triticum sativum* for the lower surface and from a maximum of 71 in *Helianthus annuus* to a minimum of zero in *Primula sinensis* on the upper leaf surface. (See Table IV.)

In Table IV I recorded the minimum, mean, average, and maximum number of stomata determined per square millimeter for each species. The average number in each case represents the average of thirty or more single counts. The minimum and maximum are rather widely separated but the mean and average are nearly always equal or nearly so.

These figures do not compare exactly with any figures found for the same species by Weiss (13), or Eckerson (5), but the differences are not so large but what they may be accounted for by differences in conditions under which the plants were grown, or different varieties or strains might have been employed by the different investigators.

In *Impatiens sultani* I found 29 stomata per square millimeter on the upper leaf surface while Eckerson reported that no stomata were found by her on the upper leaf surface of the same species. Probably I used a different variety of *Impatiens sultani*. The table also shows two sets of figures for *Pelargonium zonale*, number I was used in the first series and number II was used in the second series. These are two different varieties, the former has fewer and much larger stomata than the latter variety.

Table V records the size of the stomata for the upper and lower surface for the various species. The length and breadth of the guard cells and of the pore is recorded in microns. Each number represents the average of thirty or more measurements. I found that all the stomata as well as their pores were more or less elliptical. The length of the pore is about one half of the total length of the guard cell apparatus. (See Table V.) The width of the pore is usually less than one half its length. The largest stomata were found on the upper epidermis of *Triticum sativum*, with a pore 39 microns in length; the smallest stomata were found on the upper side of *Impatiens sultani* with a pore six microns in length. The stomata which were measured

were taken from several pieces of epidermis from several leaves from at least three plants. It was noted that individual stomata of the same plant or even leaf vary somewhat in size depending upon the part of the leaf in which they are located.

TABLE V
Showing the Length and Breadth of Stomata in Microns

Name of Species	Lower Surface		Upper Surface	
	Guard Cell	Pore	Guard Cell	Pore
<i>Phaseolus vulgaris</i>	20 X 15	8 X 3	20 X 13	11 X 3
<i>Ricinus communis</i>	26 X 18	10 X 3	22 X 15	10 X 3
<i>Zea mays</i>	36 X 27	19 X 3	33 X 19	19 X 3
<i>Primula sinensis</i>	42 X 31	20 X 4	—	—
<i>Pelargonium zonale</i> 1.....	38 X 27	20 X 4	38 X 27	17 X 3
<i>Pelargonium zonale</i> 2.....	28 X 18	11 X 3	30 X 21	12 X 5
<i>Impatiens sultani</i>	20 X 16	9 X 3	17 X 14	6 X 3
<i>Triticum sativum</i>	62 X 30	34 X 3	65 X 29	39 X 3
<i>Helianthus annuus</i>	37 X 26	19 X 4	30 X 24	14 X 3

Upon comparing the results of Tables IV and V, I noticed several general facts:

1. The size of stomata on the same plant may vary considerably with the upper and lower leaf surface.
2. In general plants with few stomata have large ones and plants with many stomata have small ones.

From the data in Tables IV and V, I computed the average number of units of stomatal pore length in microns per square millimeters of leaf area for the upper leaf surface and for the lower leaf surface by multiplying the number of stomata per unit of area by the average length of one pore. Then I computed the average number of microns of stomatal pore length for the upper and lower surfaces by adding the two values and dividing by two. The linear units of stomatal pore and not the area of the stomatal pore is important since Brown and Escombe (2) have shown that the length of the pore and not its area is important in transpiration.

I also computed the area of the stomatal pore of one stoma and then the area of the total amount of stomatal aperture per square millimeter, average of upper and lower leaf surface, by considering the stomatal pore an ellipse. (See Table VI.)

The data show that it is not necessarily the plant with the largest stomata or the plant with the greatest number of stomata that has

the largest area of stomatal aperture per unit of leaf surface. The largest number of linear units of stomatal pore, average of upper and lower surface, was found in *Helianthus annuus*, 2056 microns, and in *Zea mays*, 1530 microns, while the smallest number was found in *Pelargonium zonale*, 682 microns, and in *Impatiens sultani*, 731 microns. (See Table VI.)

TABLE VI

Showing the Number and Size of Stomata, and the Linear Units of Stomatal Pore in Microns per Square Millimeter Leaf Surface

Species	Average No. of Stomata per Sq. Mm. Surface		Average Length of Pore in Microns		Average No. of Linear Units of Stomatal Pore Average of Upper and Lower Surface in Microns per Sq. Mm.
	Lower	Upper	Lower	Upper	
<i>Phaseolus</i>	250	40	8	11	1,220
<i>Ricinus</i>	121	52	10	10	865
<i>Zea</i>	101	60	19	19	1,530
<i>Primula</i>	84	0	20	—	840
<i>Pelargonium</i> 1.....	52	19	20	17	682
<i>Pelargonium</i> 2.....	215	8	11	12	1,230
<i>Impatiens</i>	143	29	9	6	731
<i>Triticum</i>	21	46	34	39	1,254
<i>Helianthus</i>	172	71	19	14	2,056

I now arranged the several species in Table VII in the order of their greatest number of linear units of stomatal pore and also placed opposite each species in the third column the average amount of

TABLE VII

Showing Relation Between the Amount of Transpiration and Stomatal Aperture

	Linear Units of Stomatal Pore in Microns per Sq. Mm.	Amount of Transpiration per Sq. Dm. per Hour in Mg.	Area of Stomatal Aperture in Sq. Microns per Sq. Mm. of Leaf Surface
<i>Helianthus annuus</i>	2,056	156	6,433
<i>Zea mays</i>	1,530	80	3,864
<i>Triticum sativum</i>	1,254	79	2,998
<i>Pelargonium zonale</i> 2.....	1,230	65	2,868
<i>Phaseolus vulgaris</i>	1,220	156	2,890
<i>Ricinus communis</i>	865	209	1,989
<i>Primula sinensis</i>	840	75	2,614
<i>Impatiens sultani</i>	731	249	1,705
<i>Pelargonium zonale</i> 1.....	682	50	1,992

water transpired per square decimeter per hour in milligrams. This average amount of transpiration was obtained from the data in Tables II and III.

From this table (Table VII) I could determine whether any relation exists between the amount of water lost and the amount of linear units of stomatal pore. These results do not show any constant relation between the amount of transpiration and the number of linear units of stomatal pore. The two species, *Impatiens sultani* and *Ricinus communis*, both of which have a small amount of stomatal pore per unit of leaf surface, have the two highest amounts of transpiration per unit of leaf surface. *Phaseolus vulgaris* also has a high transpiration in proportion to the amount of stomatal pore per unit of leaf surface.

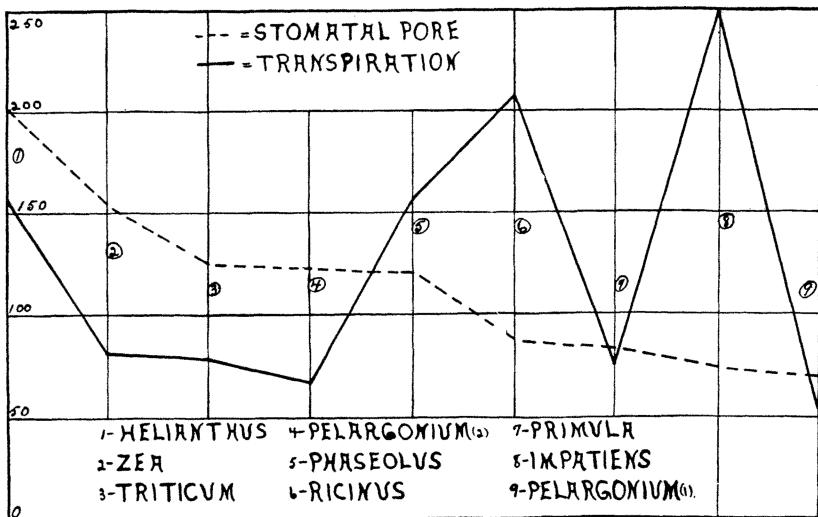


FIG. 2. Showing the amount of transpiration in mg. per hour per sq. dc. leaf surface and the number of linear units of stomatal pore in microns per sq. mm. leaf surface.

The data of Table VII are also shown in graphic form by two curves in figure 2. The two curves are drawn to separate scales. In the transpiration curve the side of each square represents fifty milligrams. In the curve showing stomatal pore the side of each square equals 500 microns. In other words the latter curve represents values ten times as large as the former, or each unit equals ten microns in the curve which represents stomatal pore.

In Table VIII I have arranged the species in the order of the

TABLE VIII
Showing Length, Area, and Amount of Transpiration for One Stoma

	Ave. No. of Stomata per Sq. Mm.	Ave. Length of Stomatal Pore in Microns	Ave. Area of 1 Stoma in Sq. Microns	Ave. Transpiration of 1 Stoma per Hour in Grams
<i>Phaseolus vulgaris</i>	145	9.5	.22	.00010
<i>Helianthus annuus</i>	122	16.5	.47	.00013
<i>Pelargonium zonale</i> 2.....	112	11.5	.35	.00006
<i>Ricinus communis</i>	87	10	.23	.00022
<i>Impatiens sultani</i>	86	7.5	.18	.00029
<i>Zea mays</i>	81	19	.48	.00009
<i>Primula sinensis</i>	42	20	.62	.00018
<i>Pelargonium zonale</i> 1.....	36	18.5	.51	.00014
<i>Triticum sativum</i>	34	36.5	.85	.00023

largest number of stomata, the average of the upper and lower surface. I also recorded the average length of the pore of one stoma in microns, the area of one stoma in square microns, and the amount of transpiration from one stoma in hundredths of a milligram.

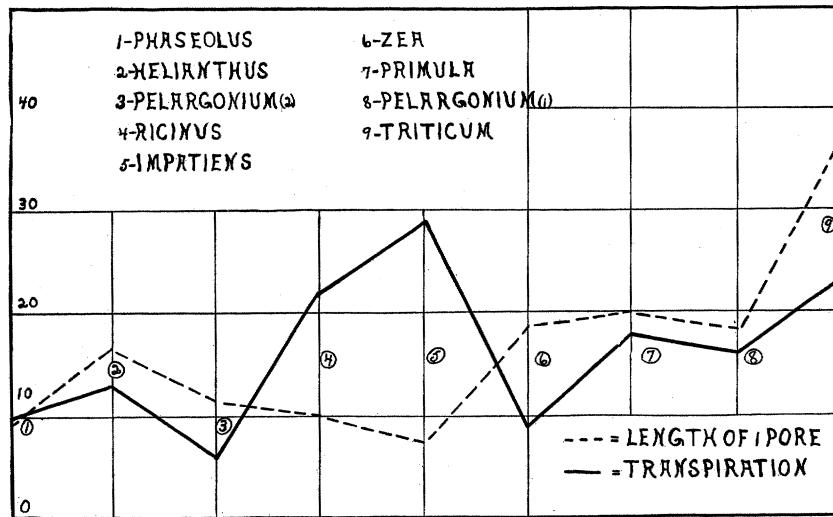


FIG. 3. Showing the length of one pore in microns, and the amount of transpiration in hundredths of mg. per hour for one stoma in the several species.

The data, namely the length of the stomatal pore and the amount of transpiration per stoma for the various species, are represented in graphic form by two curves in figure 3. These figures do not show

any relation between the length or area of the pore of a stoma and the amount of water lost for the several species.

SUMMARY

1. There was found no constant relation between the amount of water lost and the numbers of linear units of stomatal pore, *i. e.*, the number of stomata per unit of leaf surface multiplied by the length of the average pore, in the various species studied.
2. There is no relation between the amount of transpiration and the length of the pore of one stoma. The number of stomata per unit of leaf surface however varies at the same time that the length of the pore varies for the several species; so in this case we have two variables.
3. There is no relation between the amount of transpiration and the number of stomata per unit of leaf surface in the different species investigated.
4. From the above results it would seem that the amount of transpiration is not governed entirely by stomatal regulation, and that the variations in the amount of water loss in different species cannot be accounted for by the size and number of stomata but must be explained perhaps by a complex of several factors.

This investigation was suggested by and conducted under the direction of Professor Raymond J. Pool, of whose kindly advice and suggestions as well as the encouragement and suggestions of Dr. C. E. Bessey, I wish to express my sincere appreciation.

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LITERATURE CITED

1. Briggs, L. J. and Shantz, H. L. The Wilting Coefficient for Different Plants and its Indirect Determination. U. S. Dept. Agr. Bur. Pl. Ind. Bull. **230**. 1912.
2. Brown, H. T. and Escombe, F. Nature **62**: 212. 1900.
3. Burgerstein, A. Die Transpiration der Pflanzen, Jena, 1904.
4. Clapp, Grace Lucretia. A Quantitative Study of Transpiration. Bot. Gaz. **45**: 254-267. 1908.
5. Eckerson, Sophia H. The Number and Size of Stomata. Bot. Gaz. **46**: 221. 1909.
6. Freeman, Geo. P. A Method for the Determination of Transpiration in Plants. Bot. Gaz. **46**: 118. 1909.
7. Hales, Stephen. Statical Essays, Vol. I, London, 1727.

8. Livingston, B. E. and Estabrook, A. H. Observations on the Degree of Stomatal Movements in Certain Plants. Bull. Torrey Club **39**: 17-22. 1912.
9. Lloyd, F. E. Leaf Water and Stomatal Movement in *Gossypium* and a Method of Direct Visual Observation of Stomata in Situ. Bull. Torrey Club **40**: 1-26. 1913.
10. Lloyd, F. E. The Physiology of Stomata. Carneg. Inst. Washington Publ. **82**. 1908.
11. Renner, O. Beiträge zur Physik der Transpiration. Flora **100**: 451-547. 1910.
12. Sampson, A. W. and Allen, L. M. Influence of Physical Factors on Transpiration. Minn. Bot. Stud. **4**: 33-64. 1909.
13. Weiss, A. Untersuchungen über die Zahl und Grössenverhältnisse der Spaltöffnungen. Jahrb. wiss. Bot. **4**: 126-196. 1865-1866.